U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
NATIONAL METEOROLOGICAL CENTER

OFFICE NOTE 251

New Grid-scale Precipitation Package in the NMC Nested Grid Model

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OCTOBER 1982

1. Introduction

A challenge in the operational numerical modeling of grid-scale precipitation is the incorporation of the fact that such precipitation occurs in nature on a spatial scale much less than that resolvable by the forecast models. That is, this nonconvective precipitation can occur in nature in a volume represented by a grid point in a forecast model even when the mean relative humidity of that volume is less than 100%. Currently this possibility is treated in NMC's operational Limited-area Fine-mesh Model (LFM) and Movable Fine-mesh Model (MFM) by reducing the definition of saturation to less than 100%, say 90%. Alternate methods have been proposed by Mathur (personal communication), Gerrity (1981), and Phillips (1981).

This paper briefly reviews the method for grid-scale condensation in the LFM and MFM and the one proposed by Phillips (1981). Results of experiments incorporating the two techniques in NMC's Nested Grid Model (NGM) will be discussed.

2. Grid-scale Condensation in the LFM and MFM

Grid-scale condensation occurs in operational NMC forecast models, the LFM and the MFM, when relative humidity at a grid point exceeds some critical saturation value S, where S is less than 100%. That is, saturation exists if

$$q \geq S \cdot q_s, \text{ or} \tag{1}$$

$$R \equiv q/q_s \geq S, \tag{2}$$

where q is the specific humidity, q_s is the saturation specific humidity, and R is relative humidity. For example, grid-scale condensation occurs in the MFM when the relative humidity exceeds 90%. In the LFM, the saturation criterion varies seasonally, from 90% in the summer to 96% in the winter.

The primary reason for using this method is that it enables some condensation to occur when the volume represented by a grid point in the forecast model is not completely saturated. Thus, the onset of precipitation is earlier than when full saturation is required.

There are several disadvantages, however, with this method. As pointed out by Phillips (1981) and Mathur (1981), the effective value of the latent heat of condensation is reduced, the equivalent potential temperature of the moist adiabat used in the cumulus convection is less, and the onset of grid-scale condensation is still sudden, albeit earlier. Additionally this technique requires special preprocessing and postprocessing. Initial relative humidities must be reduced to the value of S to prevent heavy precipitation in the first time step of the forecast. In the postprocessing the predicted relative humidities are inflated by dividing them by S so that the resultant range of relative humidities is from 0 to 100%.

3. Grid-scale Condensation by the Phillips Method

The method proposed by Phillips (1981) is one of several techniques to overcome the objections to the LFM/MFM method for determining grid-scale condensation. In the Phillips method the volume represented by each grid point is assumed to have a uniform distribution of relative humidities ranging from $R(1-\varepsilon)$ to $R(1+\varepsilon)$ with an average relative humidity of R, the value for the grid point. The quantity ε determines the range of the relative humidity distribution. In contrast to the relative humidity, we assume that the temperature and pressure in the volume surrounding the grid point are the same as at the grid point.

For a given value of R at a grid point, three degrees of saturation can exist.

Case I: No saturation. In this case the average relative humidity (that is, the grid-point value) is below the threshold for condensation,

$$R \leq \frac{1}{1+\varepsilon} \quad . \tag{3}$$

Case II: Total saturation. The entire volume represented by the grid point is saturated,

$$R \geq \frac{1}{1-\varepsilon} \quad . \tag{4}$$

The resultant temperature T' and specific humidity q' following adjustment of the saturated grid volume with temperature T and average specific humidity q are given by the following equations, if we assume a constant-enthalpy isobaric adjustment at pressure p to a final state with 100% relative humidity:

$$T' = T + \beta\ (q - q_s), \tag{5}$$

$$q' = q - c_p\ (T' - T)\ /\ L\ . \tag{6}$$

Here L is the latent heat of condensation, c_p is the specific heat capacity of air at constant pressure, q_s is the saturation specific humidity, R_v is the gas constant for water vapor, and e_s is the saturation vapor pressure. Also,

$$\beta^{-1} = \frac{c_p}{L} + \alpha q_s \quad , \tag{7}$$

where

$$\alpha = \left(\frac{p}{p - 0.378\ e_s} \right) \frac{L}{R_v T^2} \quad . \tag{8}$$

Case III: Partial saturation. This case occurs when

$$\frac{1}{1+\varepsilon} < R < \frac{1}{1-\varepsilon} \quad . \tag{9}$$

A portion of the grid volume is saturated and a portion is not. The fraction f of the volume that is saturated, for the uniform distribution of q assumed, is

$$f = \frac{q\,(1+\varepsilon) - q_s}{2\,\varepsilon q} = \frac{R\,(1+\varepsilon) - 1}{2\varepsilon R} \quad . \tag{10}$$

The analogous equations to (5) and (6) for this case are derived by averaging the temperature and specific humidity adjustments over the grid volume to obtain

$$T' = T + \beta q \varepsilon f^2 \quad , \tag{11}$$

$$q' = q - c_p (T' - T) / L \; . \tag{12}$$

Note that care must be taken in the practical application of the Phillips method in determining which of the three cases applies for a given grid volume. If the value of f, for example, is used to determine the case instead of R in (3), (4), and (9), then q must be greater than zero and ε cannot be zero, or else the use of (10) will lead to numerical problems. In the NGM, we constrain q to be no smaller than 10-6 gm/gm and test on $f\varepsilon$ to determine which of the three cases applies.

The Phillips method has the benefit of the LFM/MFM method in that grid-scale condensation begins sooner than if total saturation were required for condensation. The Phillips method has several benefits over the operational scheme:

1) the onset of grid-scale precipitation is gradual,
2) the moist adiabat used in the convective parameterization will not be artifically constrained to a cooler value, and

3) special postprocessing of the relative humidity is unnecessary.

Disadvantages to the Phillips method are not significant. Compared with a model in which the grid-point relative humidity must reach 100% for saturation, the coding is slightly more complicated, yet the complexity is certainly less than that of the LFM/MFM method when one includes the post-processing of the latter. Second, the effective value of the latent heat of condensation is reduced as it also is in the method specifying a saturation criterion less than 100%.

4. Experimental Results

The results of three forecasts using the NMC Nested Grid Model are presented here to compare the effect of two methods for formulating grid-scale condensation: the method in which the saturation criterion is reduced and the method of Phillips (1981). In Forecast A a saturation criterion S of 90% was used in the NGM. The saturation criterion S was set at 100% in Forecast B, so that total saturation was required in a grid box represented by a grid point before condensation could occur. The Phillips method was used in Forecast C with $\varepsilon = 0.05$. Comparison of Forecasts A and B indicates the effect of reducing the saturation criterion S from 100%, whereas comparison of Forecasts B and C shows the effect of allowing a gradual onset of precipitation by the Phillips method. Comparing Forecasts A and C indicates whether the LFM/MFM method and the Phillips method yield similar results.

The parameterization of cumulus convection was identical in all three experiments. Differences that evolve during the forecast owing to differences in the grid-scale condensation formulations, however, will influence the convection, which in turn can influence the grid-scale condensation.

The case selected for study was 0000 GMT 17 May 1981. The operational Hough analysis provided the initial fields for the NGM forecasts. Figure 1 presents the synoptic situation. An important precipitation forecast problem for the continental U.S. at this time was a surface low in the central U.S. and the accompanying upper-air closed low (Collins et al., 1981). There were two other significant weather producers--a maritime air mass with occluded low approaching the West Coast and a low pressure system in New England.

The evaluation consisted of 2 parts: 1) a subjective comparison of the forecast charts and 2) a comparison of grid-to-station verification statistics for the three forecasts.

a. Comparison of Forecast Charts

The numerical forecasts at 12-h intervals through 48-h were compared, as displayed in formats similar to those of the LFM 4-panel chart. At the 12-h point, there was no noticeable difference in the mass field among the three forecasts, as indicated by the 700-mb height, 500-mb height and vorticity, surface pressure, and 1000/500-mb thickness. The only apparent differences were in the moisture-related parameters. The mean relative humidity for the lower troposphere was very similar in all three runs, with the exception that several areas with relative humidities greater than 90% in Forecasts B and C had values less than 90% on Forecast A. This is to be expected because the saturation criterion S was 90% in Forecast A, and these values were not inflated during postprocessing by dividing by S, as is done with the operational LFM. The predicted accumulated precipitation from 0-12 h was only slightly different among the three forecasts (Figure 2). During this 12-h period all precipitation was generated through grid-scale condensation. Forecast A had the most rain and Forecast B the least, although the differences were minor. The areal coverage was a little larger in Forecast A over the North Pacific. Thus, although the onset of precipitation was modeled differently in the three forecasts, no significant differences existed among the 12-h forecasts.

Through 24 h the mass-field forecasts continued to be very similar. In light precipitation areas, the precipitation from 12-24 h tended to be the heaviest in Forecast A and the lightest in Forecast B (Figure 3). In the heavier precipitation areas of the Midwest and southeastern U.S., however, generalization is more difficult. For instance, the rain over eastern Nebraska was actually forecast to be heaviest in Forecast B and lightest in Forecast A, whereas the order is just the opposite for the system in northern Alabama. The 50% relative-humidity isopleth through the central and southeastern U.S. is similar in all three runs (Figure 4). The 70% isopleth differs markedly, however, between Forecast A and Forecasts B and C. Inflation of the relative humidity by dividing by the saturation criterion S in Forecast A would make this run more similar to the other 2 runs in the central U.S., but would reduce the similarity that exists with the system entering the Pacific Northwest. The precipitation from 12-24 h was entirely grid-scale, except for the systems in Nebraska and in the Gulf of Mexico, where convection contributed 20% of the total.

At 36 h the 500-mb height forecasts were very similar. Differences began to appear in the mean-sea-level pressure prediction, however, as the pressures in the Mississippi-Alabama area were 3-4 mb lower in Forecast A. In all three runs, the model was in the process of developing a fictitious mesoscale storm here in response to the initial analysis, in which temperaature and dewpoint near the earth's surface were several degrees too warm near the Gulf Coast. The anomalous storm was just developing sooner in Forecast A. The accumulated rain from 24-36 h was heaviest in Forecast A and lightest in Forecast B, even over Nebraska in contrast to the previous period. Areal coverage was similar in all runs, with it being slightly greater in Forecast C and slightly less in Forecast B. During this time no precipitation was convective, except in the southeastern U.S., where 50% of the total was due to convection.

Even at 48 h the mass-field forecasts were very similar. As Figure 5 shows for the 500-mb height and vorticity, the only obvious difference is in the absolute vorticity associated with the fictitious system in the southeastern U.S. The areal coverage of precipitation from 36-48 h was very similar in all runs. Rainfall in Forecast A was very slightly heavier than Forecasts B and C, which had very similar amounts. As was true from 24-36 h, the rainfall occurring from 36-48 h was due to grid-scale condensation, except in the southeastern U.S., where 50% was convective.

b. Verification Statistics

All three forecasts were verified from 0-48 h with actual observations of the 110-station North American verification network used at NMC. Results for several forecast fields are presented in Table 1. Because of the abovementioned deficiencies in the Hough moisture and temperature analyses for this case, especially along the Gulf Coast, the actual error magnitudes are of little consequence. Contrasting the errors of the three forecasts,

Table 1. S1 score, mean error, and standard deviation (s.d.) error for Forecast A (saturation criterion S = 90%), Forecast B (S = 100%), and Forecast C (Phillips method with ε = 0.05). The 110-station North American network was used for verification. Initial conditions were derived from the Hough spectral analysis for 0000 GMT 17 May 1981.

Forecast Variable		Forecast Time														
		0 h			12 h			24 h			36 h			48 h		
		A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
mean sea level pressure	S1	----	----	----	31.1	31.4	31.3	45.8	45.1	45.4	47.5	46.6	46.8	56.3	53.8	54.7
850-mb temperature (°K)	mean	-0.7	-0.7	-0.7	0.0	-0.1	-0.1	-1.0	-1.2	-1.2	0.1	-0.1	-0.1	-1.2	-1.4	-1.4
	s.d.	2.4	2.4	2.4	2.5	2.5	2.5	3.8	3.7	3.7	3.0	3.0	3.0	4.2	4.1	4.2
500-mb height (m)	mean	-5.2	-5.2	-5.2	13.4	12.6	12.8	-3.9	-5.7	-5.1	1.4	0.2	0.7	-3.7	-6.5	-6.0
	s.d.	12.2	12.2	12.2	17.8	17.6	17.6	17.9	18.1	18.0	23.9	22.8	22.9	23.9	23.4	23.4
250-mb wind vector (m/s)	mean	7.2	7.2	7.2	8.7	8.7	8.7	10.5	10.5	10.5	11.1	10.6	10.7	11.7	11.7	11.7
	s.d.	4.1	4.1	4.1	4.9	4.9	4.9	5.3	5.6	5.5	6.2	5.7	5.8	6.7	7.0	7.1

however, indicates impact on forecast accuracy of the grid-scale condensation schemes.

We find that the differences in the error statistics are small and of mixed sign. That is, none of the forecasts was significantly better.

5. Summary and Conclusions

Two techniques for formulating the grid-scale condensation process were compared. One technique is currently used operationally at NMC in the LFM and MFM and involves the specification of a saturation criterion less than 100%. Grid-scale condensation occurs when this saturation criterion is exceeded to return the relative humidity to the saturation criterion. No condensation occurs unless the criterion is exceeded. The second method, presented by Phillips (1981), permits grid-scale condensation over a range of relative humidities. The range includes relative humidities less than 100%.

The case of 0000 GMT 17 May 1981 was used to study the sensitivity of NMC's Nested Grid Model to the two formulations of grid-scale condensation. This case included several regions of grid-scale precipitation and one intense region involving both grid-scale and convective precipitation.

Forecasts made for this one case indicated no significant advantage of either formulation. All forecast differences as seen in the forecast charts through 48 h were minor, especially in the mass fields -- heights of pressure surfaces and mean sea level pressure. A slightly greater amount of precipitation was forecast in the operational formulation with a 90% saturation criterion than in the one by Phillips with $\varepsilon = 0.05$, and there was a slightly greater amount of rain forecast in the latter than in the operational formulation with a saturation criterion of 100%. Areal coverage of precipitation was not significantly effected by the different formulations of grid-scale condensation. These minor differences between forecast charts were supported by the verification statistics, which indicated no superiority of any of the forecasts.

Therefore, the replacement of the method for grid-scale condensation using a saturation criterion with the Phillips method did not significantly alter the performance of the Nested Grid Model for the 17 May 1981 case. We see no reason why this should not be true for additional cases and other models -- the truth of which can only be determined through additional testing. Methods of the general nature of the Phillips (1981) technique are appealing when compared with the saturation criterion method because the onset of grid-scale precipitation is gradual, the moist adiabat used in the convective parameterization is not artifically constrained to a cooler value, and there is no need for special postprocessing of relative humidity.

6. References

Collins, W., D. Deaven, J. Gerrity, R. Hirano, J. Hoke, M. Mathur, J. Newell, 1981: Regional model intercomparison. Development Division report, National Meteorological Center, National Weather Service (NOAA), Camp Springs, Maryland.

Gerrity, J. P., 1981: Large-scale (that is, grid-scale) condensation. Informal note, National Meteorological Center, National Weather Service (NOAA), Camp Springs, Maryland, 4 pp.

Mathur, M. B., 1981: A note on the use of lower saturation mixing ratio criteria for release of latent heat in NWP models. Office Note 248, National Meteorological Center, National Weather Service (NOAA), Camp Springs, Maryland, 15 pp.

Phillips, N. A., 1981: A simpler way to initiate condensation at relative humidities below 100 percent. Office Note 242, National Meteorological Center, National Weather Service (NOAA), Camp Springs, Maryland, 14 pp.

Figure Captions

Figure 1. Initial fields for the NGM forecasts from 0000 GMT 17 May 1981:

a) 500-mb height (solid line, contour interval = 60 m) and absolute vorticity (dashed line, contour interval: 2×10^{-5}/s),

b) mean sea level pressure (solid line, contour interval = 4 mb) and 1000/500-mb thickness (dashed line, contour interval: 60 m), and

c) 700-mb height (solid line, contour interval = 30 m) and lower tropospheric relative humidity (dashed line, contour interval: 20%. Areas with relative humidities greater than 70% are shaded).

Initial conditions were the same for all forecasts, with the exception that relative humidity in excess of 90% was truncated to 90% in Forecast A.

Figure 2. The predicted accumulated precipitation from 0-12 h (solid line, units: 0.01 in, contour interval: 0.50 in) and vertical velocity at 12 h (dashed line, contour interval: 2×10^{-3} mb/s, positive for upward motion) for

a) Forecast A (saturation criterion S = 90%),

b) Forecast B (S = 100%), and

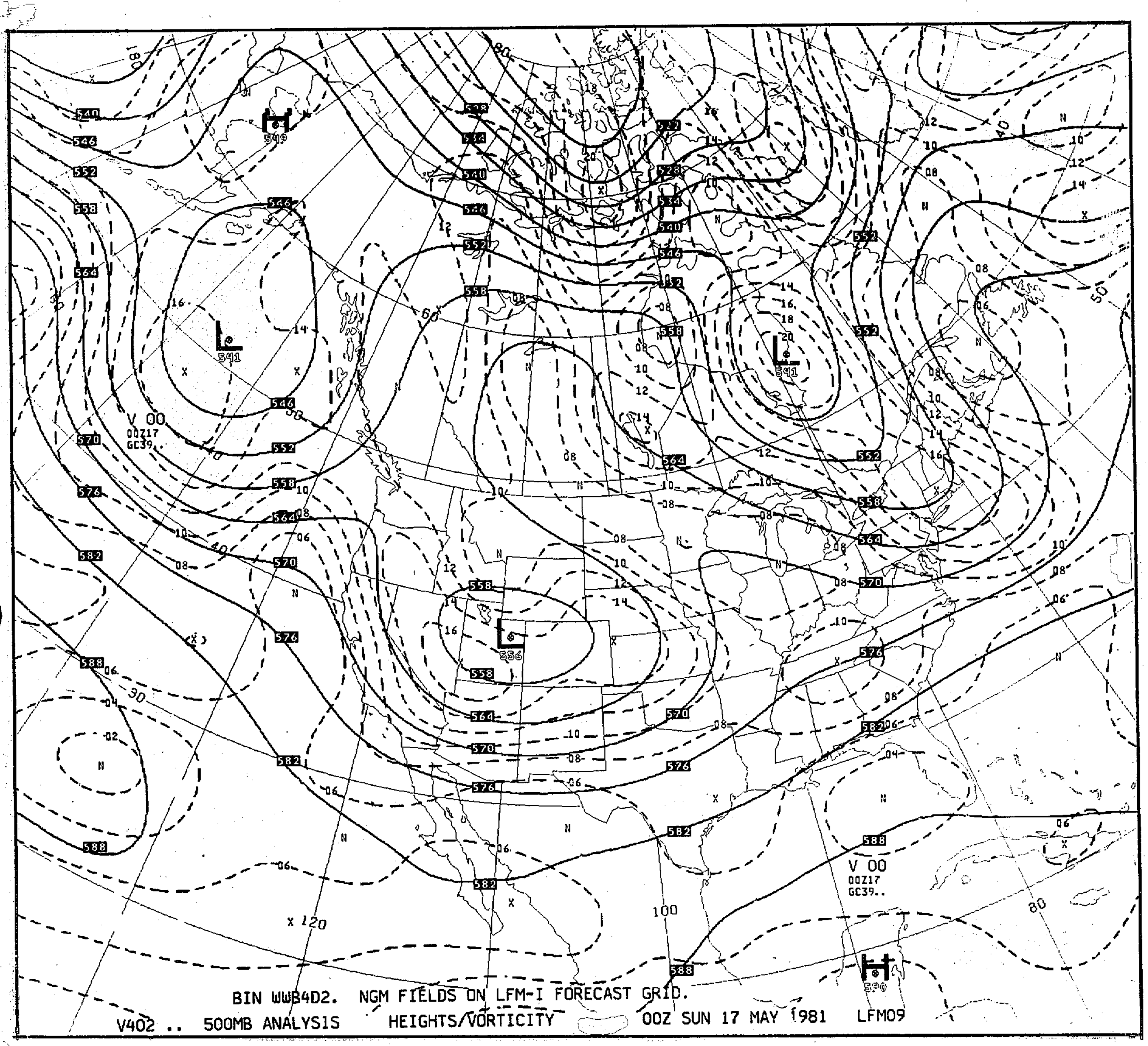
c) Forecast C (Phillips method with ϵ = 0.05).

Figure 3. Same as Figure 2, except for 12-24 h.

Figure 4. The 700-mb height (solid line, contour interval: 30 m) and lower tropospheric relative humidity (dashed line, contour interval: 20%) for the 24-h forecast valid at 0000 GMT 18 May 1981 for

a) Forecast A, b) Forecast B, and c) Forecast C.

Figure 5. The 500-mb height (solid line, contour interval: 60 m) and absolute vorticity (dashed line, contour interval: 2×10^{-5}/s) for the 48-h forecast valid at 0000 GMT 19 May 1981 for a) Forecast A, b) Forecast B, and c) Forecast C.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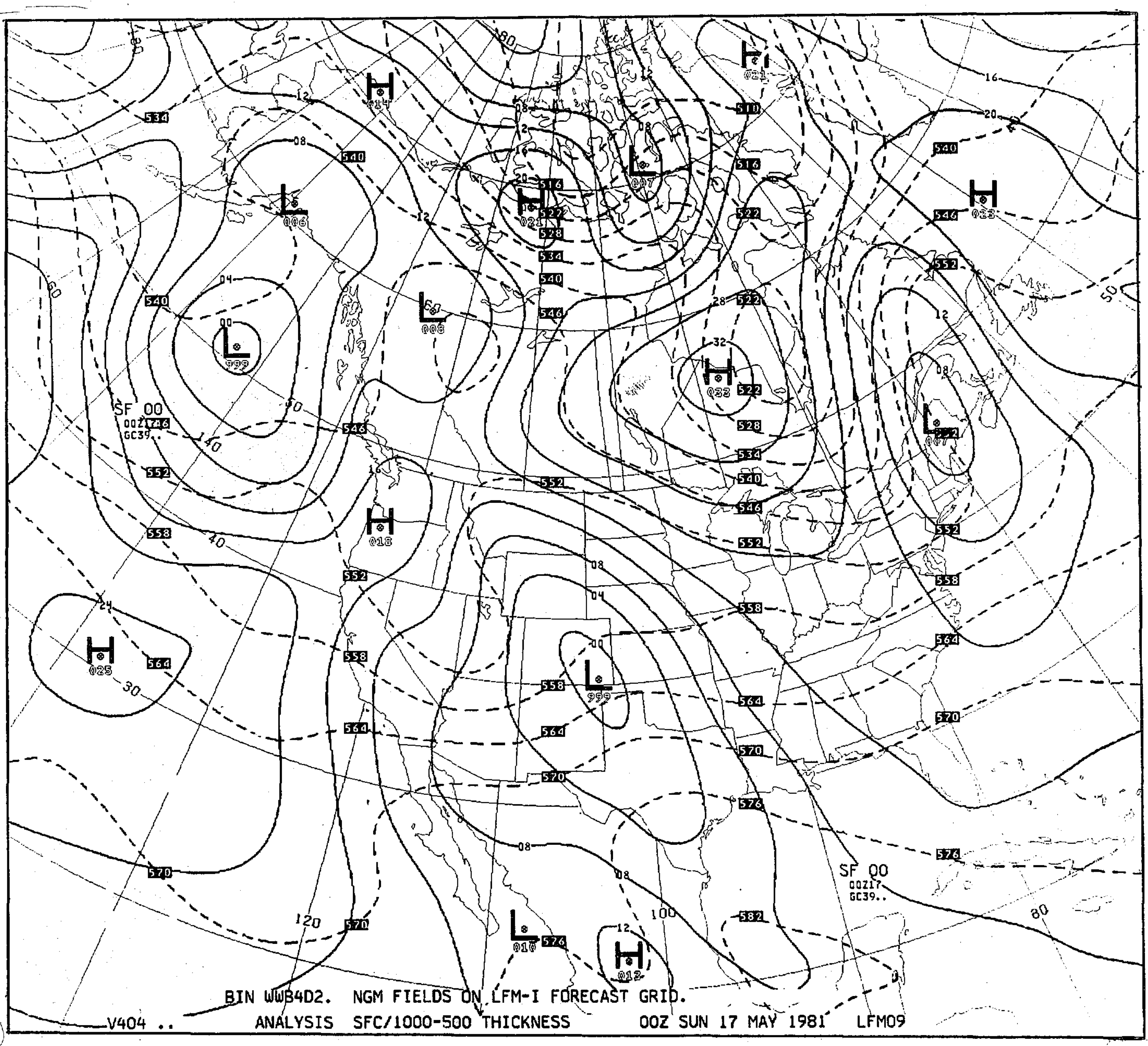
V 00
00Z17
GC39..

Figure 1 a)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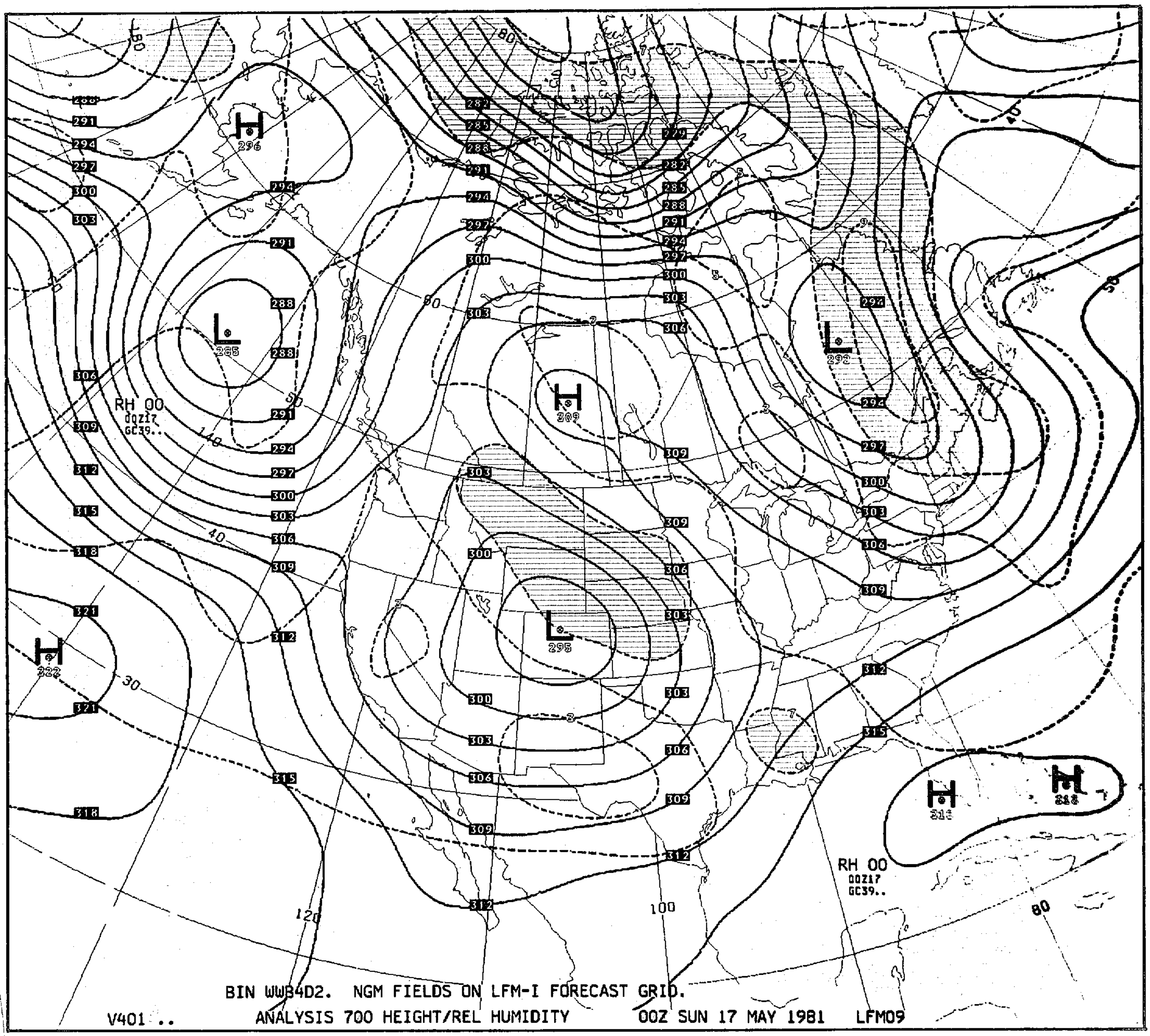
00Z17
GC39..

Figure 1 b)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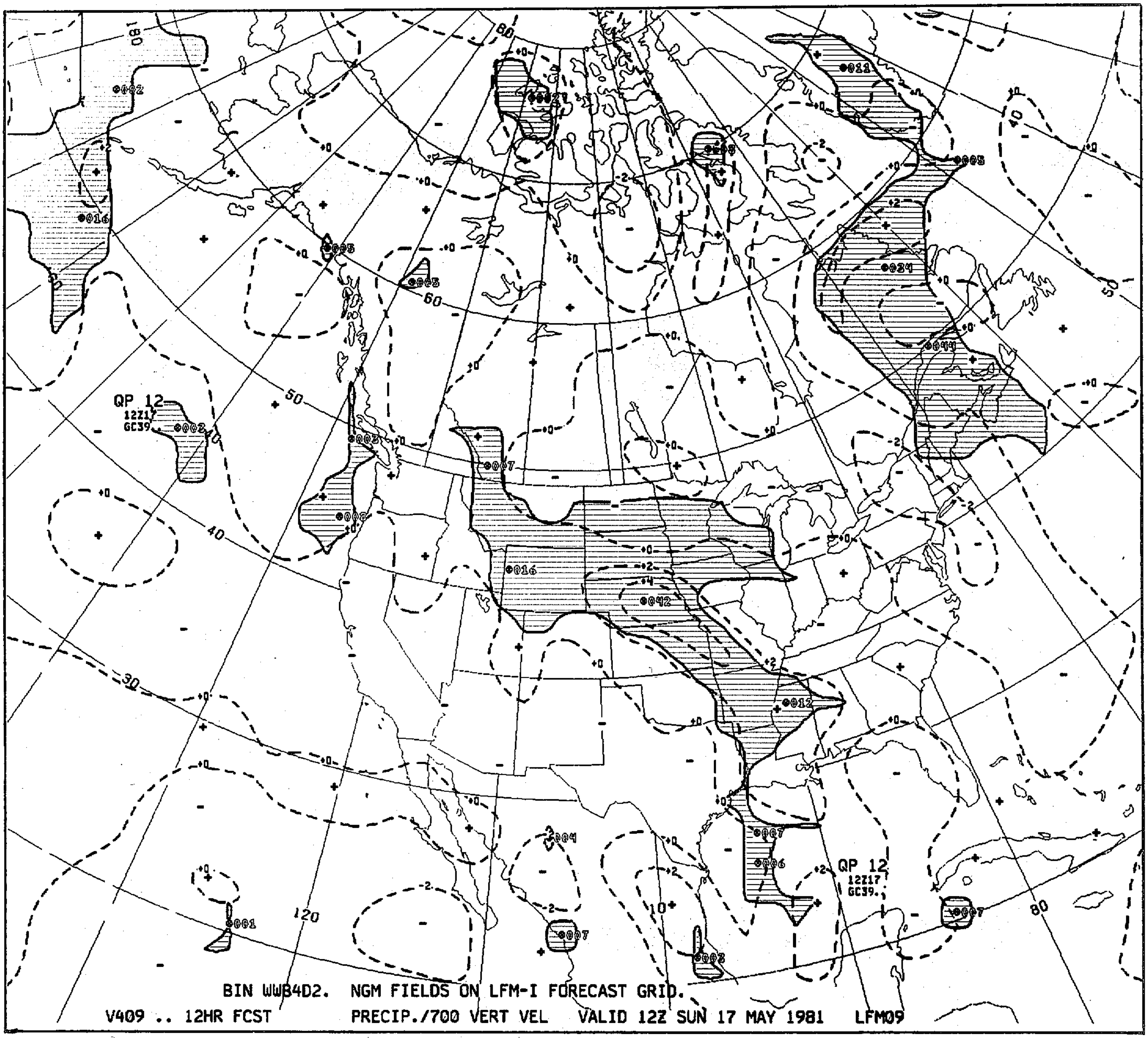
ANALYSIS 700 HEIGHT/REL HUMIDITY
00Z SUN 17 MAY 1981
LFM09
RH 00
RH 00

Figure 1 c)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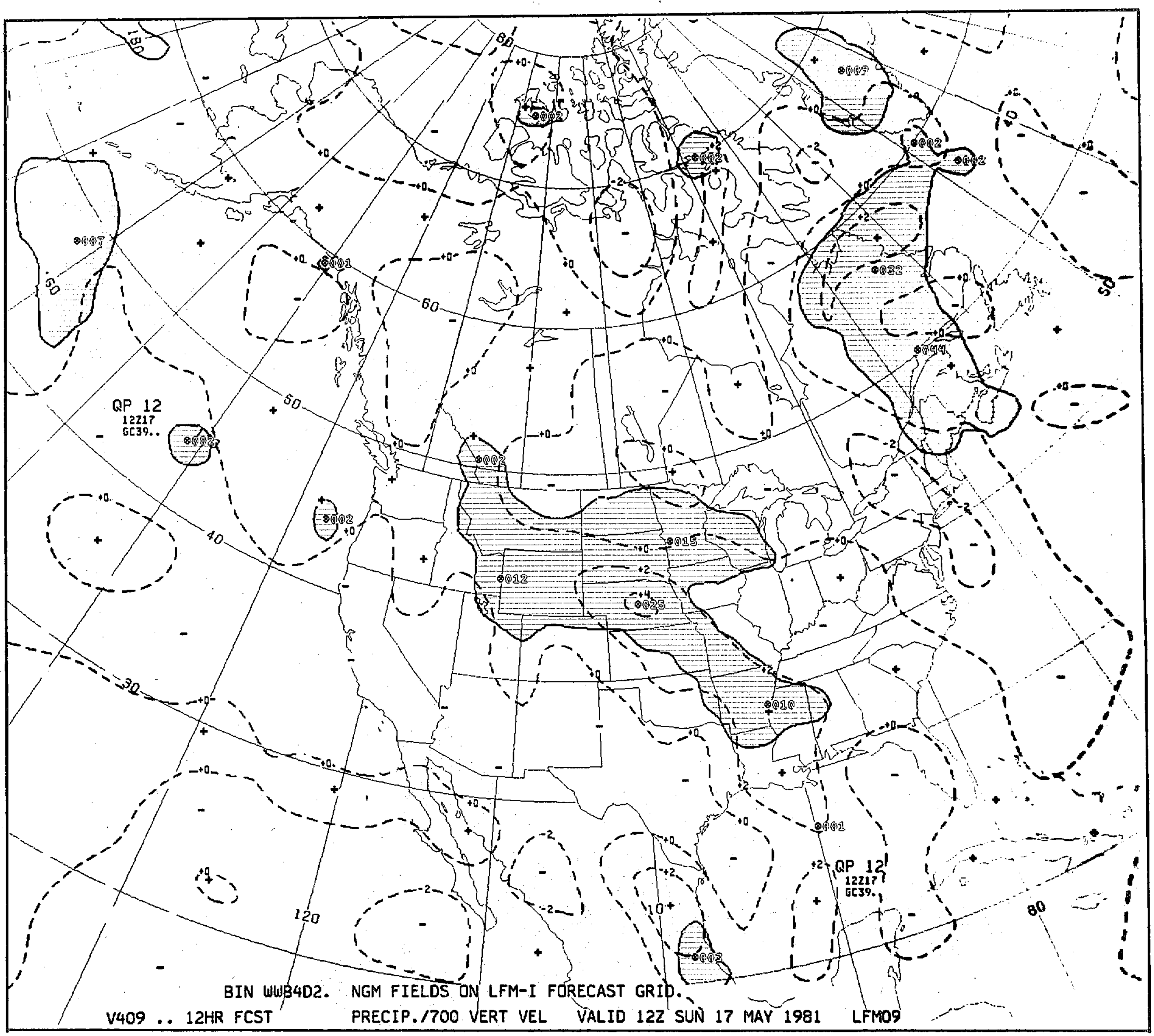
12Z17
GC39..

Figure 2 a)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QP 12
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GC39.
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Figure 2 b)

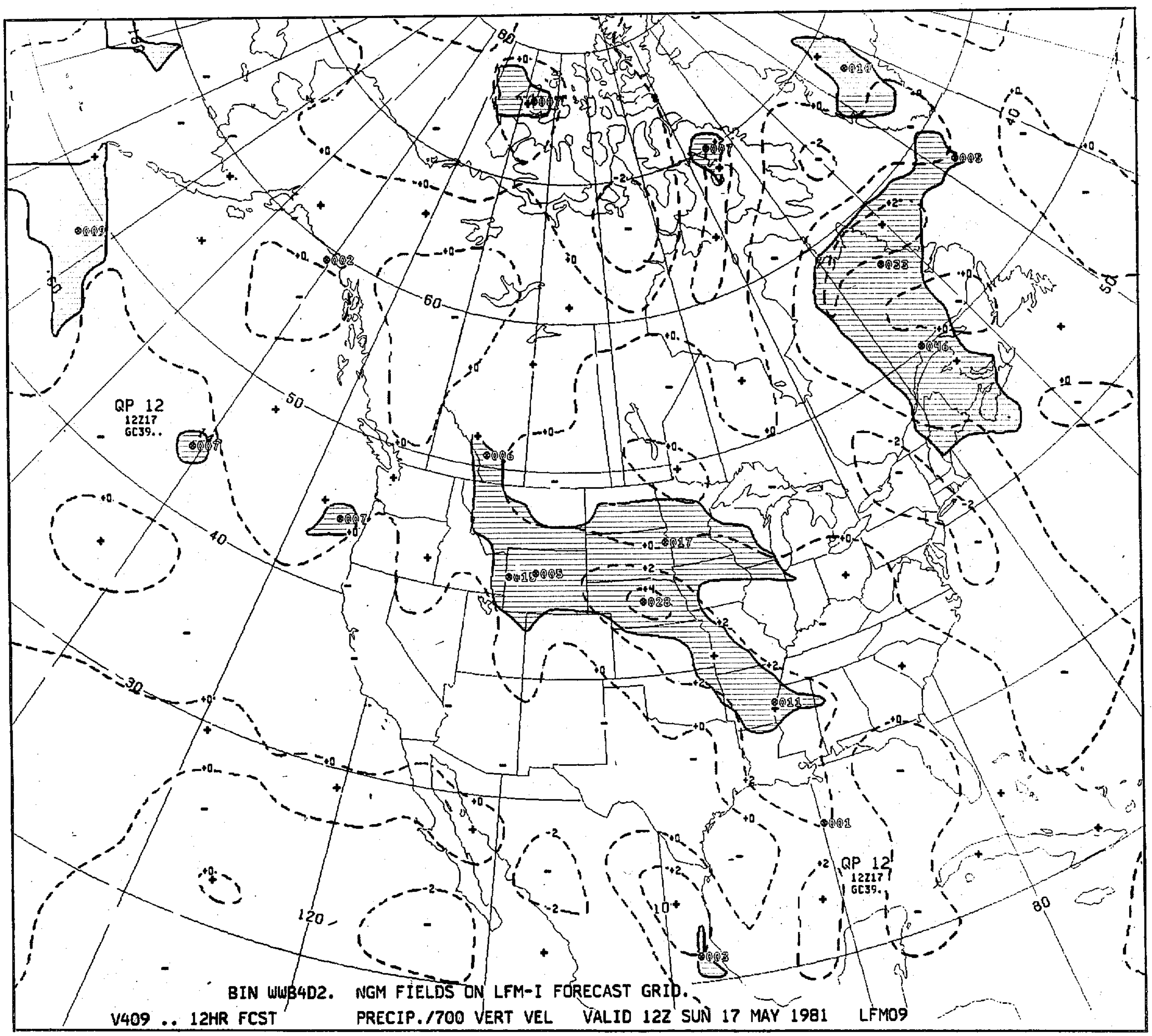
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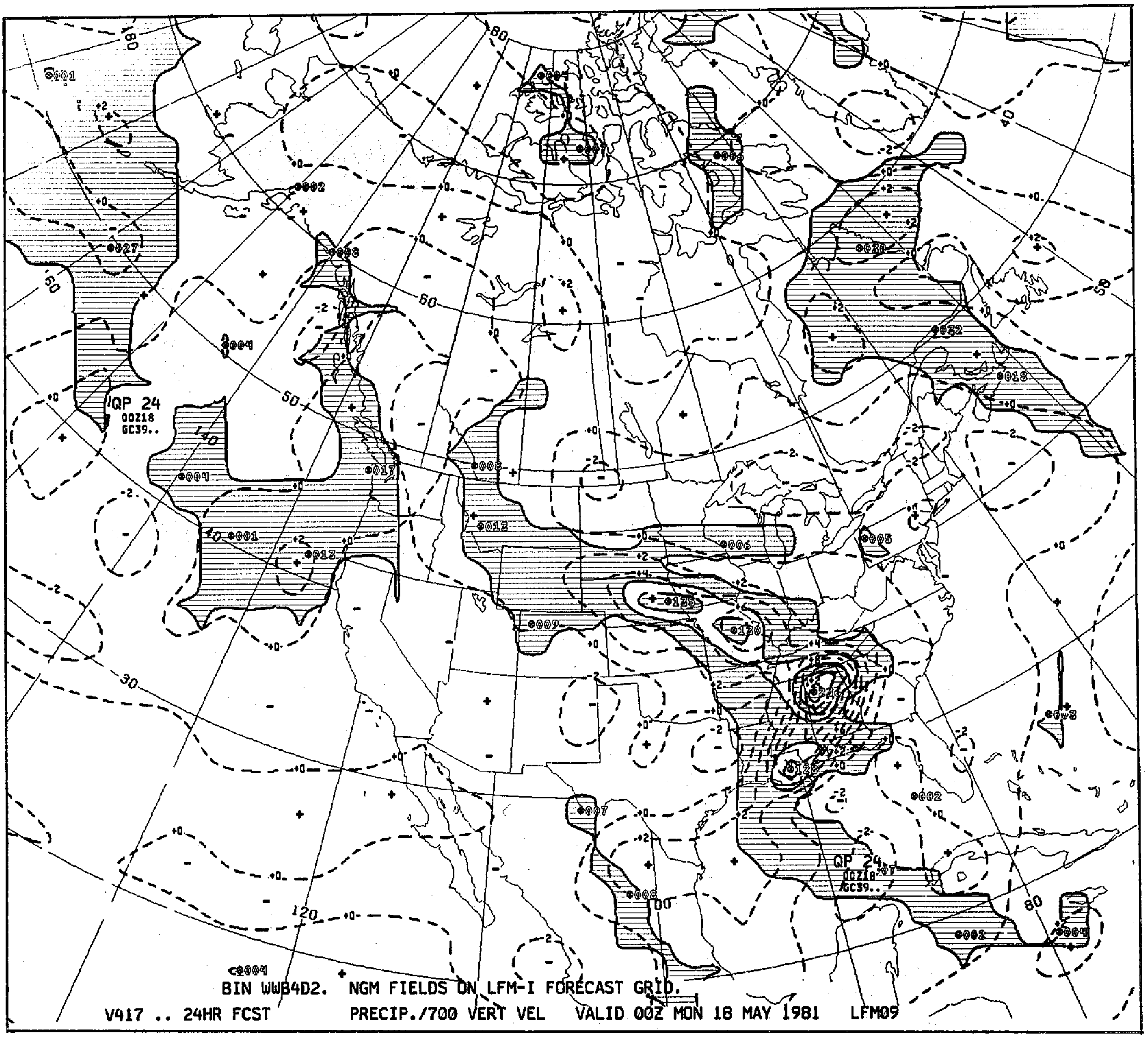
Figure 2 c)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V417 .. 24HR FCST PRECIP./700 VERT VEL VALID 00Z MON 18 MAY 1981 LFM09

Figure 3 a)

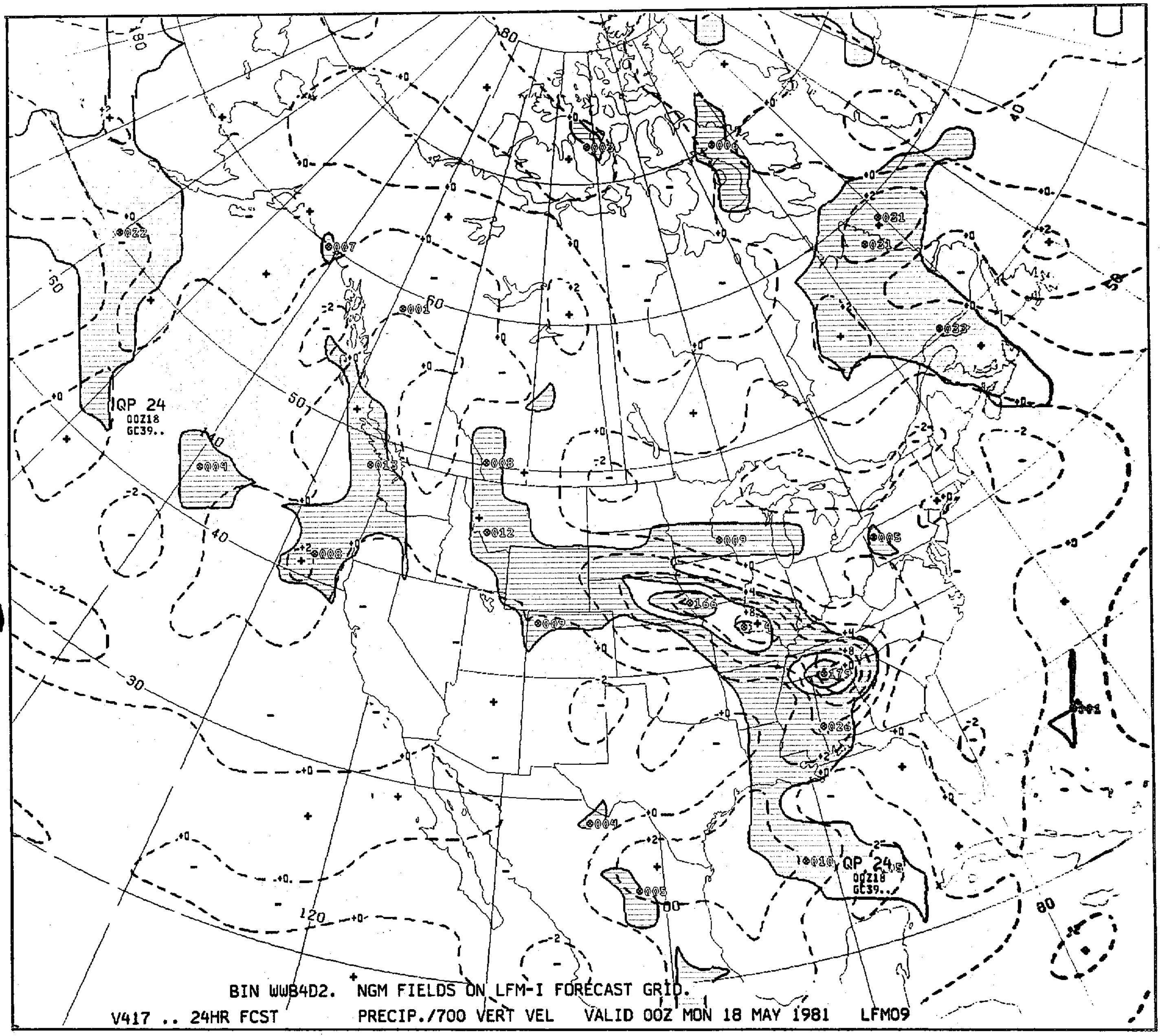
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Figure 3 b)

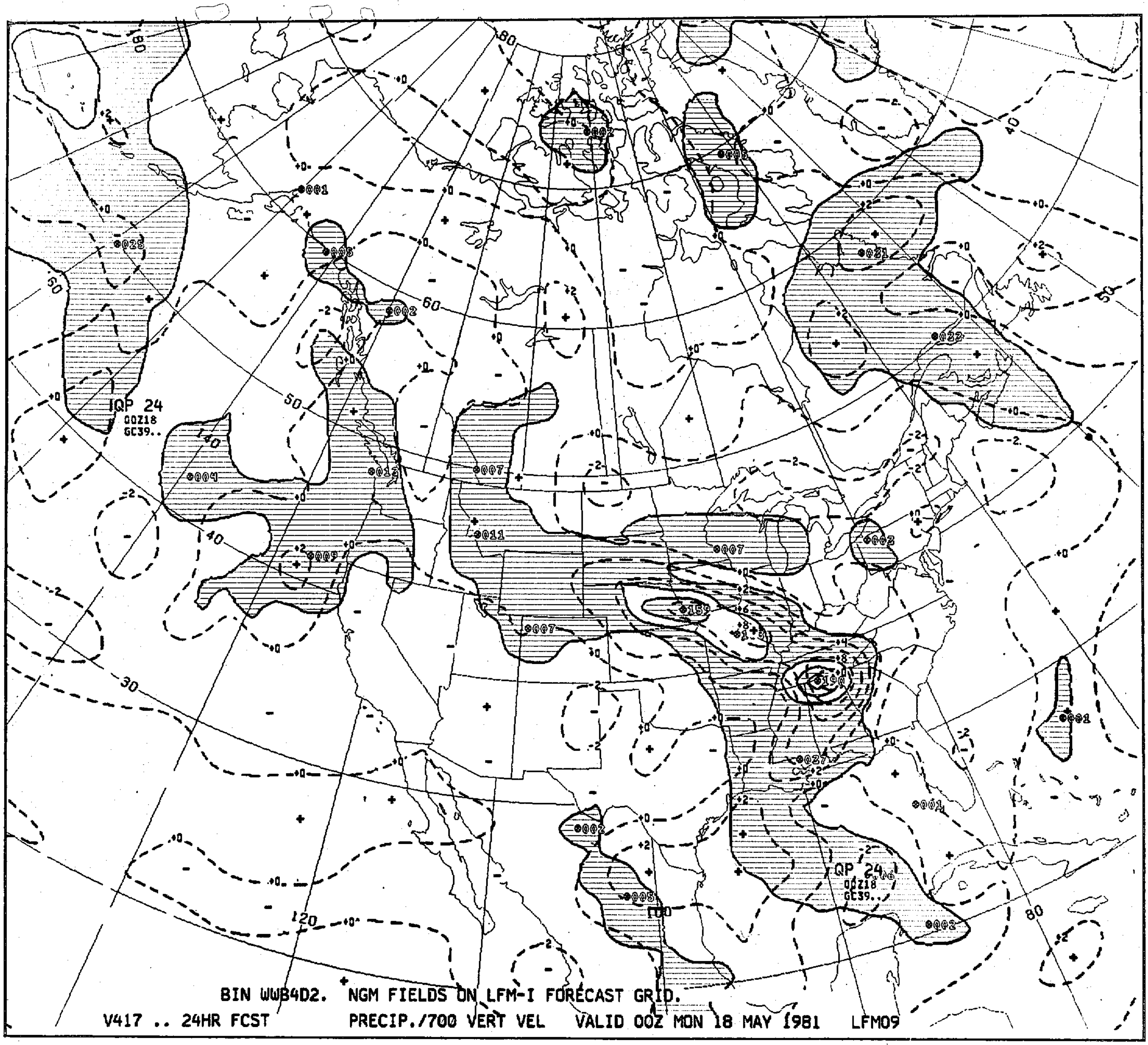
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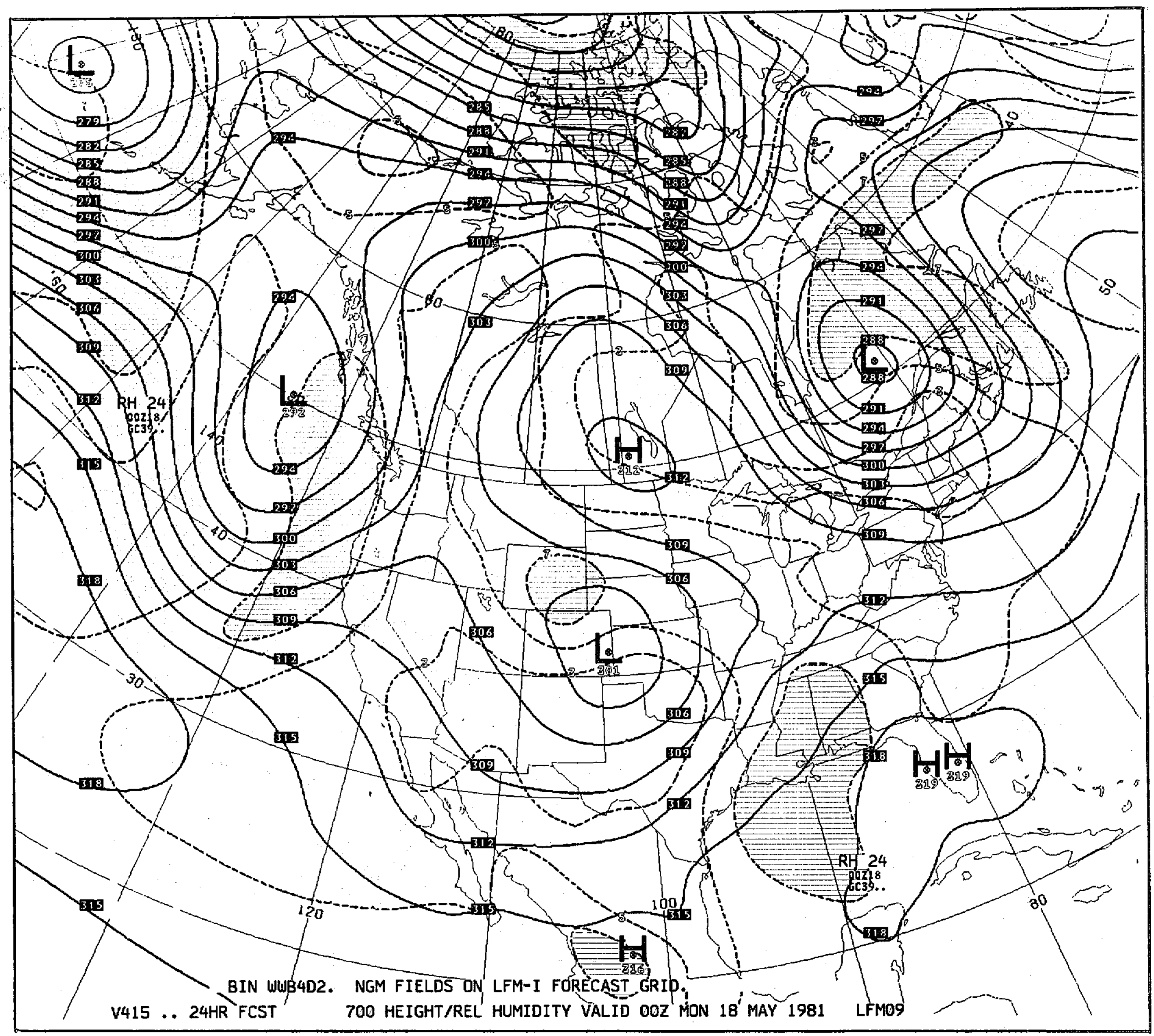
Figure 3 c)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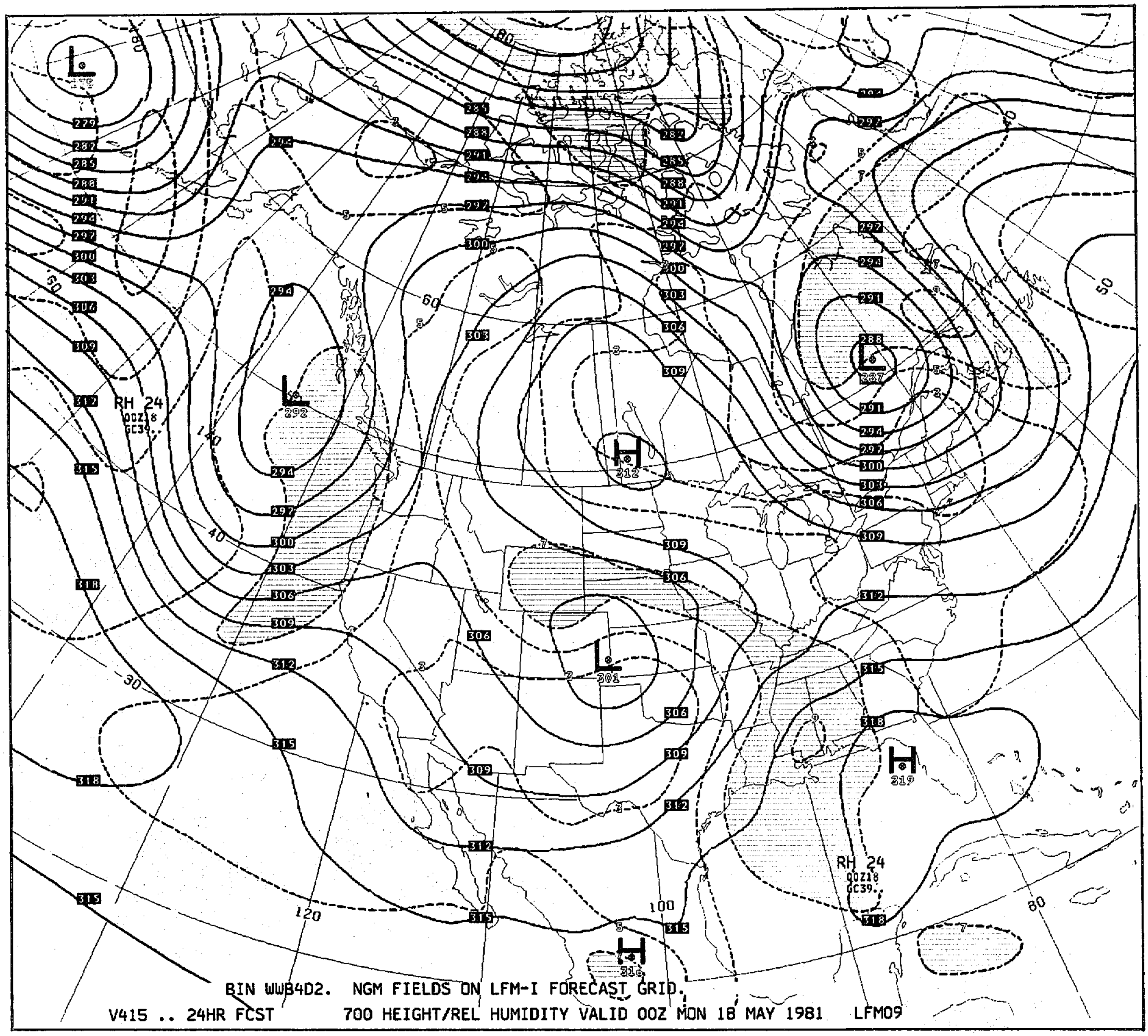
GC39..

Figure 4 a)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GC39.

Figure 4 b)

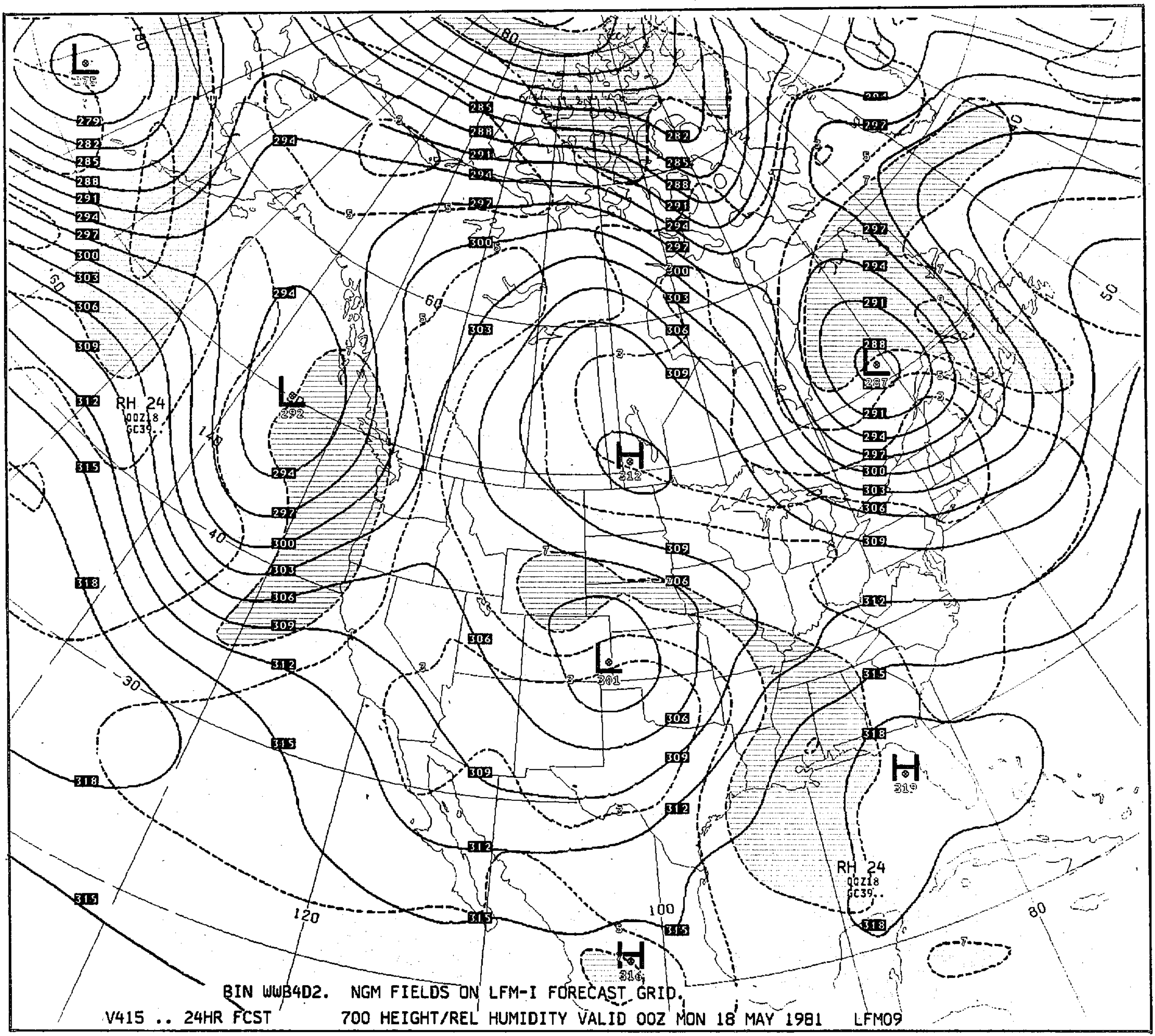
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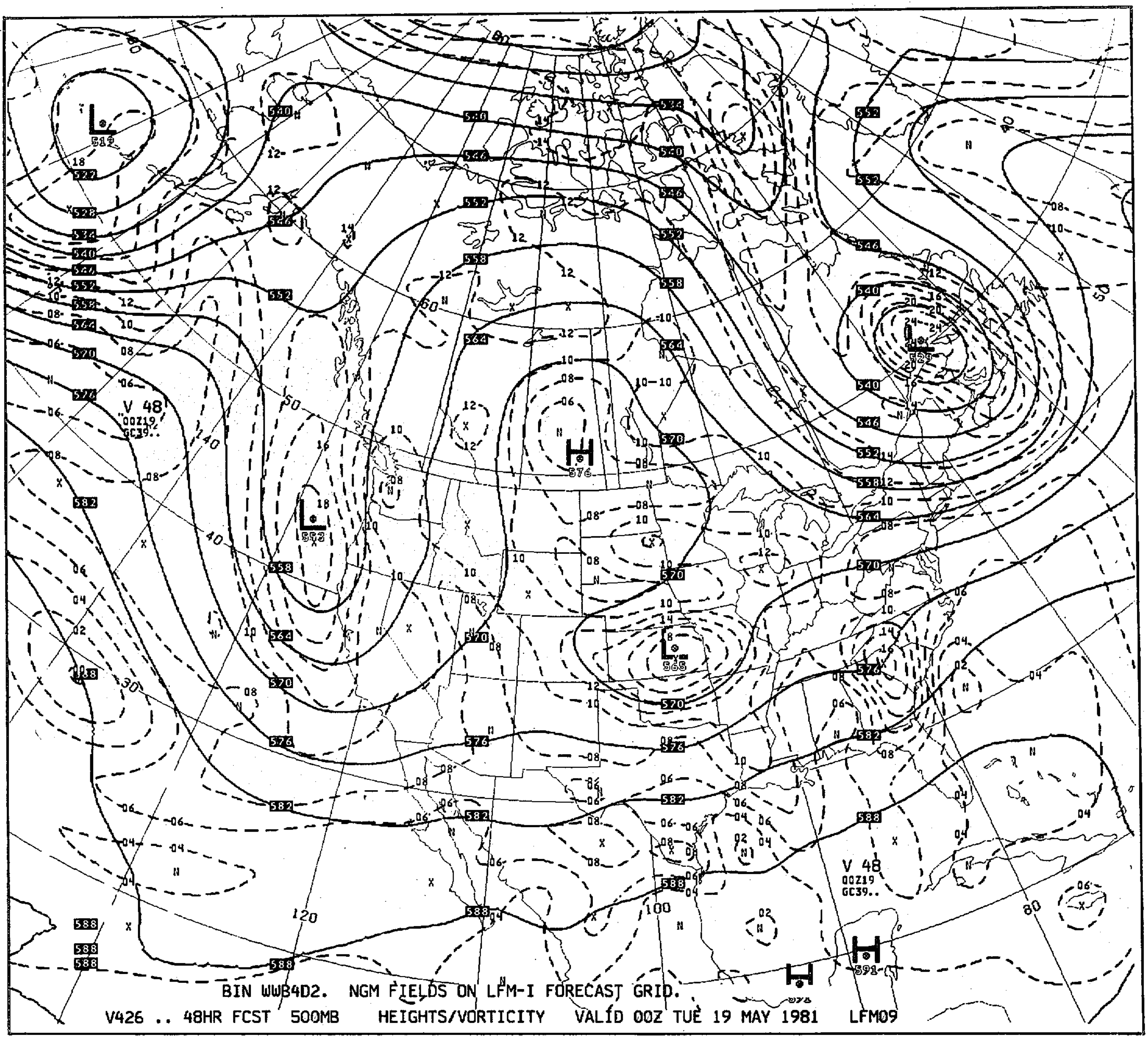
Figure 4 c)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00Z19
GC39..

Figure 5 a)

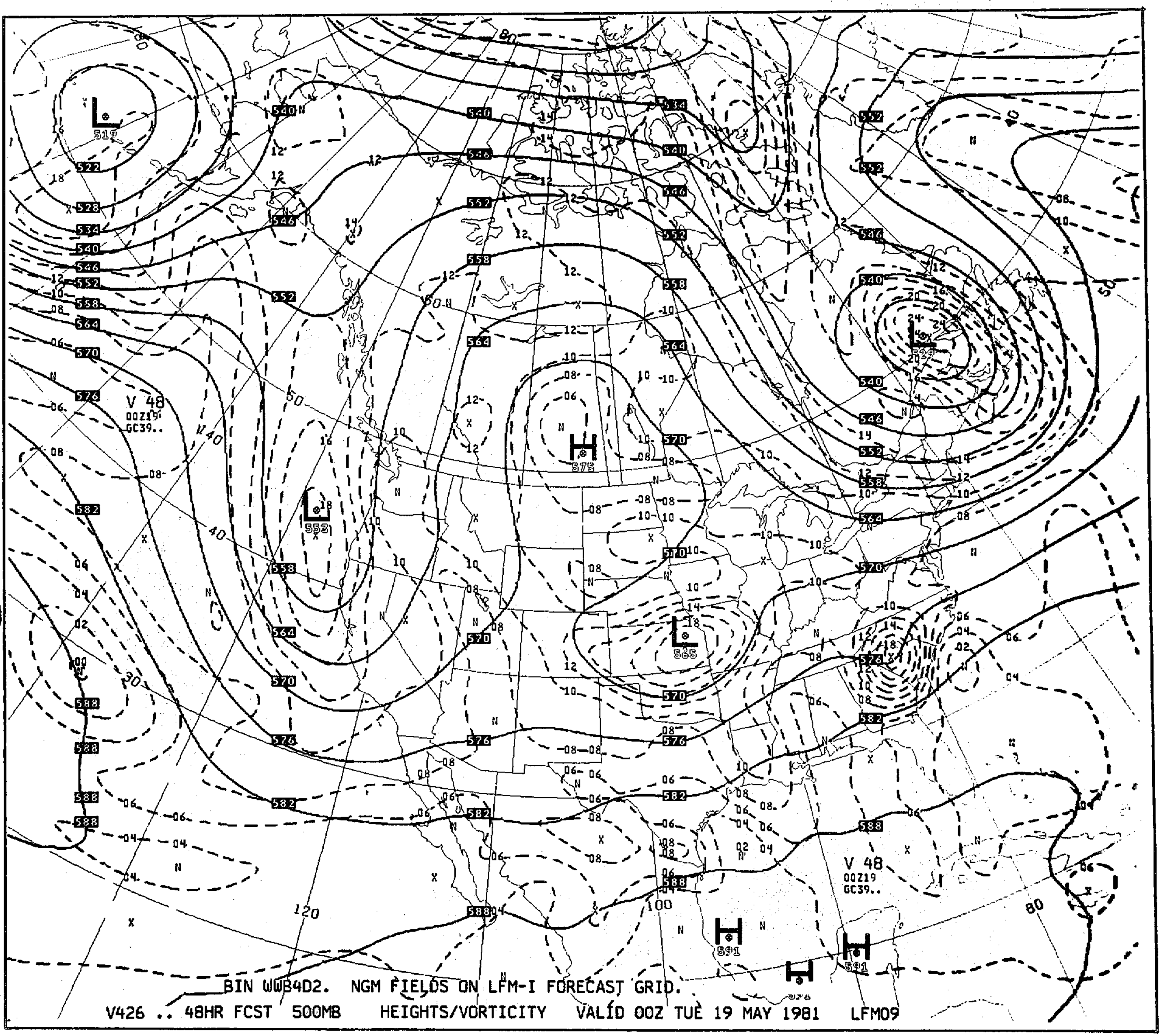
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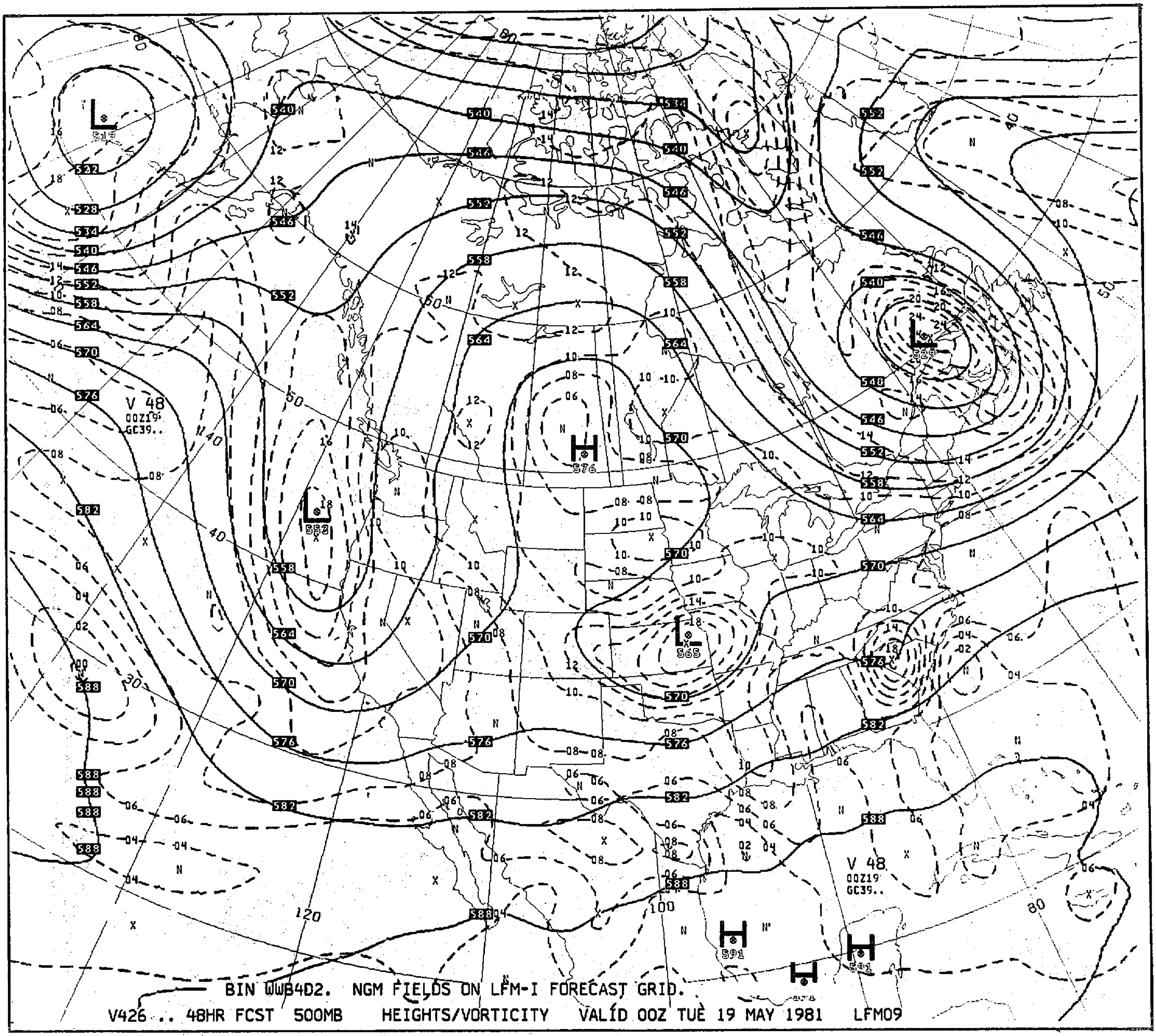
Figure 5 b)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V426 .. 48HR FCST 500MB HEIGHTS/VORTICITY VALID 00Z TUE 19 MAY 1981 LFM09

Figure 5 c)